Plasma based XUV Sources for Metrology Applications

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2017 EUV Source Workshop, 8.11.2017, Dublin

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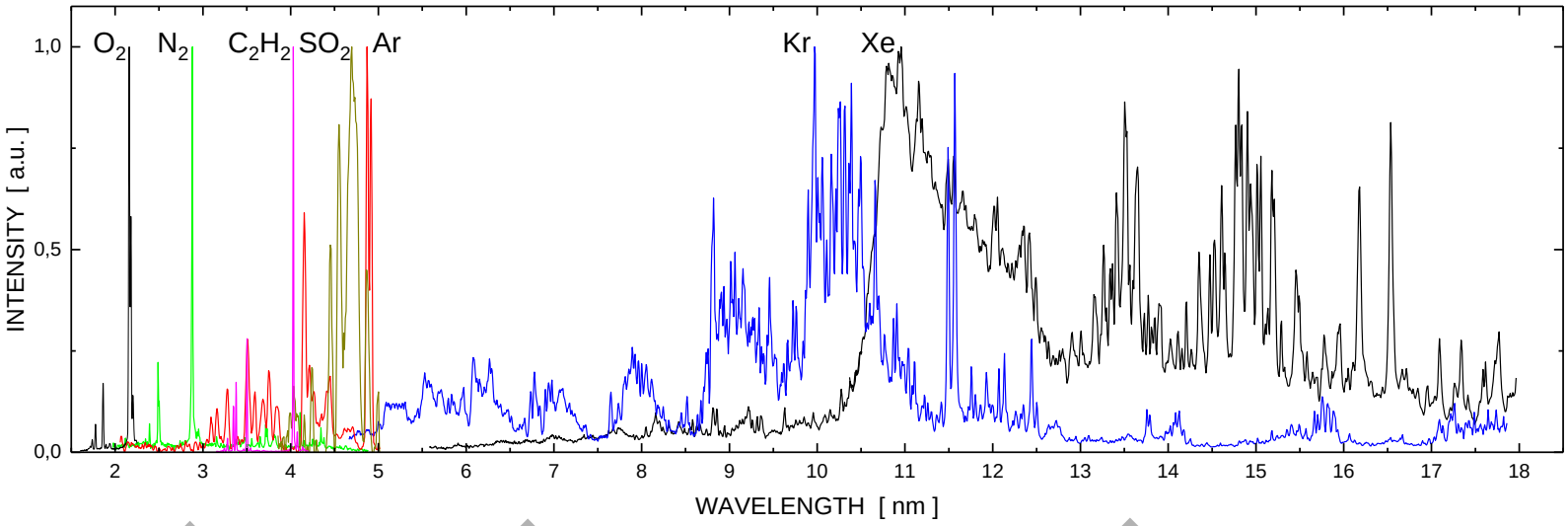
Current activities on XUV sources at ILT

Water window | Beyond EUV | 13.5 nm



- single line for x-ray microscopy
- „broadband" emission for surface analysis tools

- technical solution for regenerative LPP targets
- identification of efficient emitter
- metrology sources

- sources for inspection
- optimization of brightness and power scaling at 13.5 nm
- increase of long term stability

This Paper !

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Consideration on 6.x nm emitter for LPP

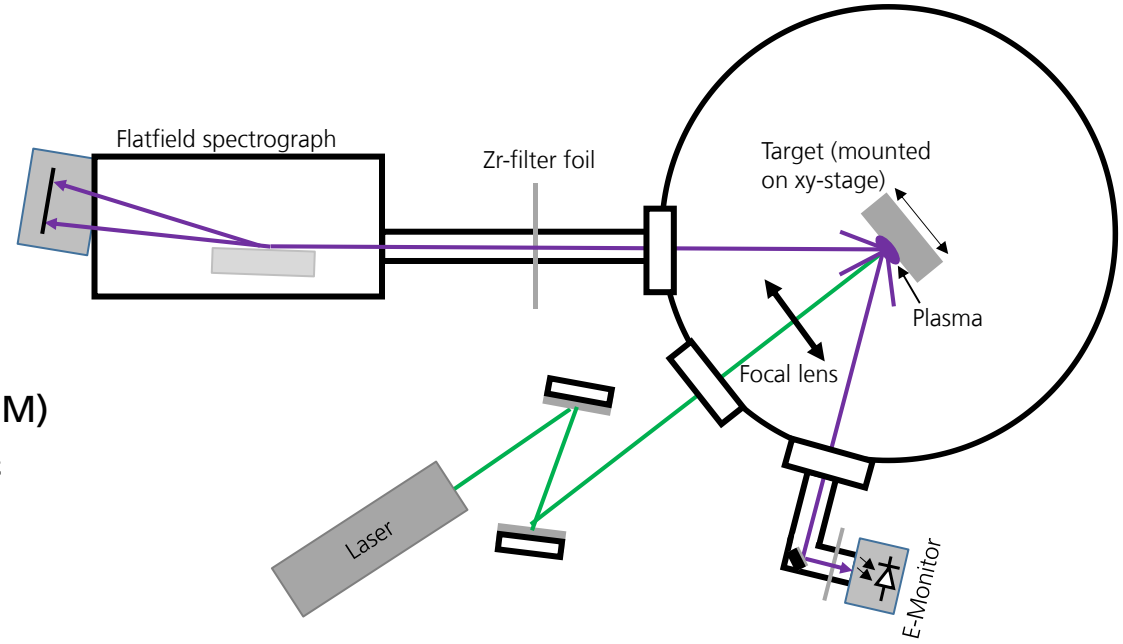
	Ionisation levels	Comments
Gd	~ XV – XXV	• Known as efficient emitter due to UTA's around 6.x nm • High melting point (T_m > 1300°C) • Not practical for liquid/regenerative targets
Tb	~ XIV – XXIV	
Al	~ VII – X	• Lower melting point compared to Gd/Tb • "Many" resonance lines within 5 – 8 nm • Line emission better matched to small ML bandwidth
Mg	~ VIII – XI	
Xe	~ X	• Gaseous emitter suited for DPP sources • Broadband emission around 6.x nm • Less efficient compared to Gd/Tb
Kr	~ IX	

Experimental Set-up: Comparison of 6.x nm emitter

Experiments in cooperation with
Rhein Ahr Campus (Remagen)

Coherent infinity laser:

- Wavelength: **532 nm**
- Pulse energy: **~140 mJ**
- Pulse length: **3 ns**
- Rep.-rate: **10 Hz**
- Typical focus size: **40 µm** (FWHM)
- Typical intensity: **3×10^{12} W/cm²**



HOCHSCHULE KOBLENZ
UNIVERSITY OF APPLIED SCIENCES
RheinAhrCampus

institute for x-optics
iXO

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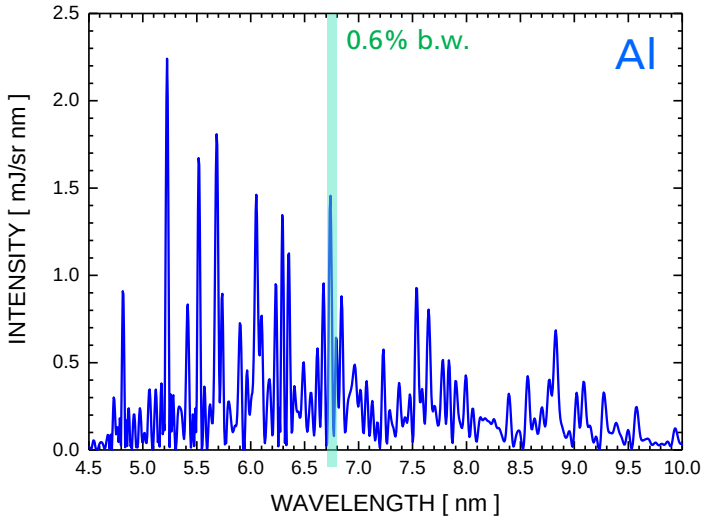
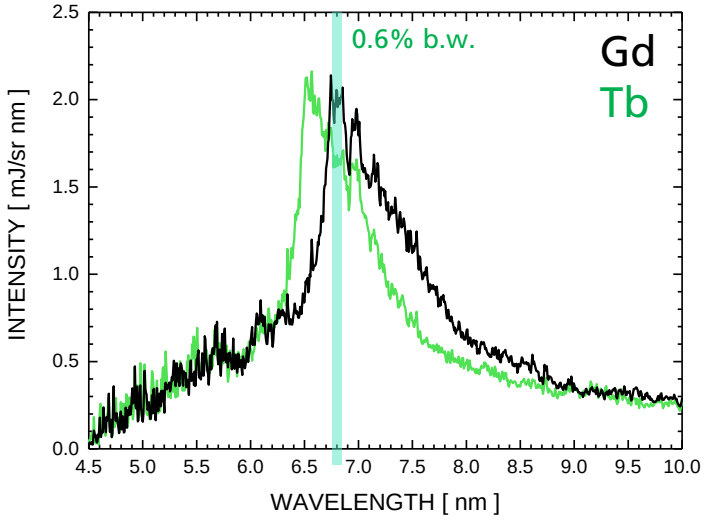
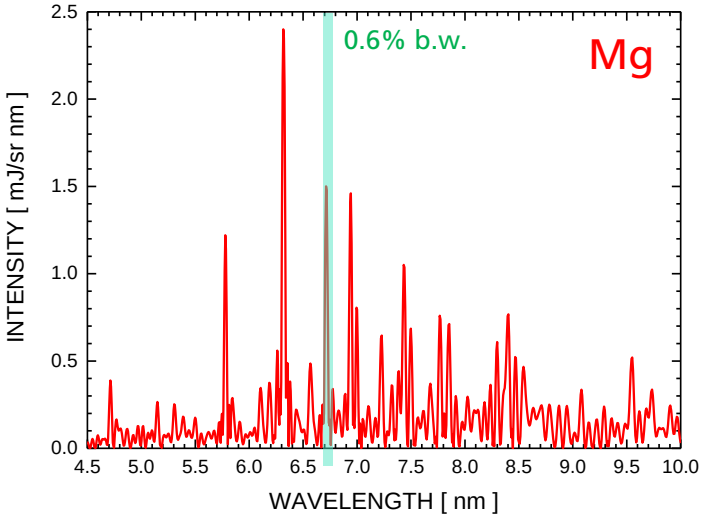
Result 6.x nm: Alternative emitter for LPP

- Gd/Tb emission comparable to literature data for λ_{laser} = 532 nm
  CE ~ 0,25%/(2πsr 0.6 % b.w) @ 6.7 nm
- similar peak brightness in lines for Al and Mg







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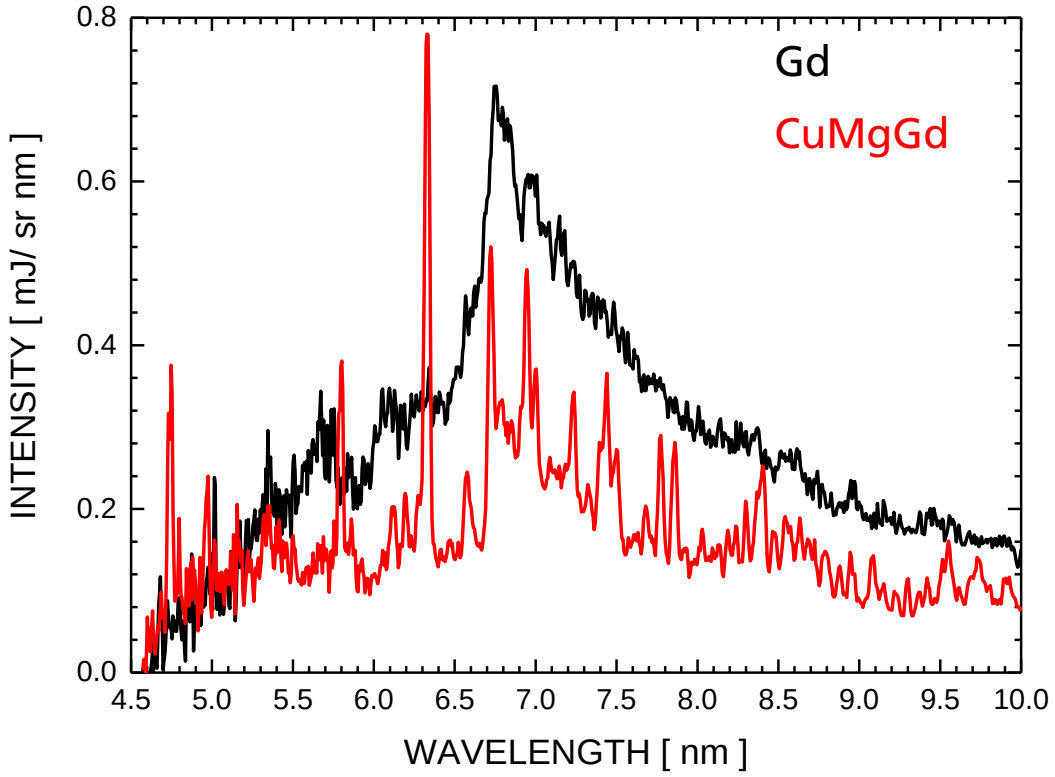
LPP emission spectra: Comparison Gd/CuMgGd

Melting point of CuMgGd :

< 500°C

- Same conditions for both targets
- Gd emission of alloy is reduced by factor 2
- Gd ion density in alloy is reduced by factor >>2 (2% atomic density)
- Behavior in agreement with theoretical considerations
- Strong line emission from Mg at 6.7 nm



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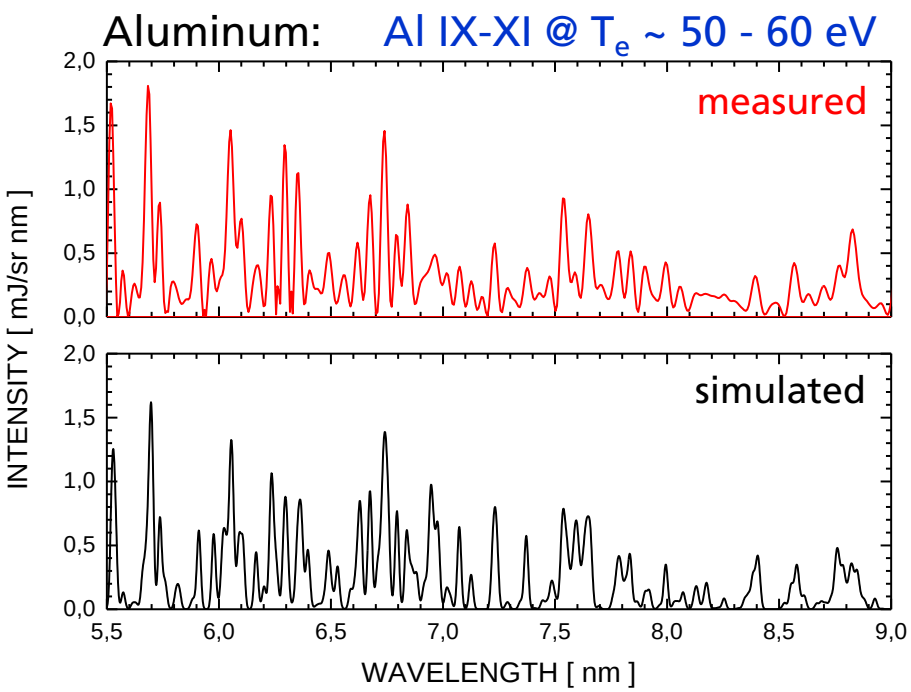
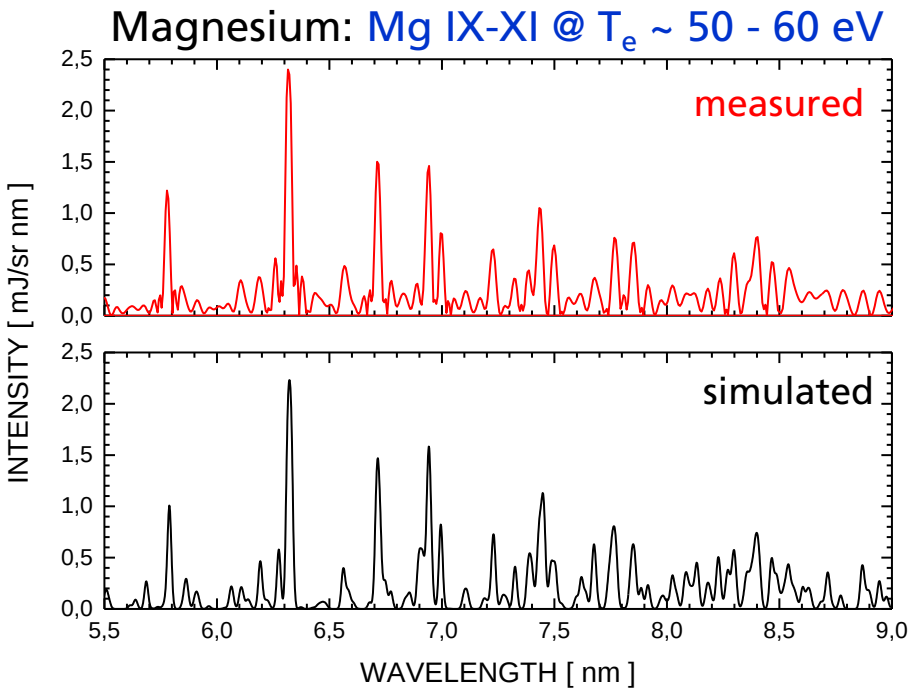
Simulation of emission spectra (Al, Mg)





Spectral radiance :

$$L(\lambda) = \frac{j(\lambda)}{\chi(\lambda)} \cdot (1 - e^{-\chi(\lambda)d})$$

$$j(\lambda) = \sum_i j^i(\lambda) = \sum_i \frac{hc}{4\pi\lambda} A^i_{ul} n^i_u f^i(\lambda)$$

$$\chi(\lambda) = \sum_i \chi^i(\lambda) = \sum_i \frac{h\lambda}{c} (B^i_{lu} n^i_l - B^i_{ul} n^i_u)\, f^i(\lambda)$$

u: upper level

l : lower level

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Discharge based XUV Source: 13.5 nm inband emission

Xenon based FS5440
(13.5 nm, 2 % b.w.)

- Inband Power: **> 40 W/2πsr**
- EUV pulse energy: > 4 mJ/sr
- Typ. repetition rate: 1500 Hz
- Avg. peak brightness: 12 W/mm²sr

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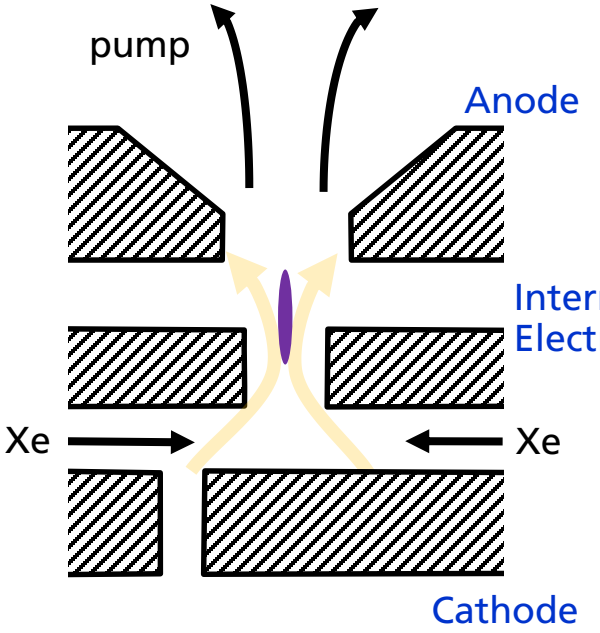
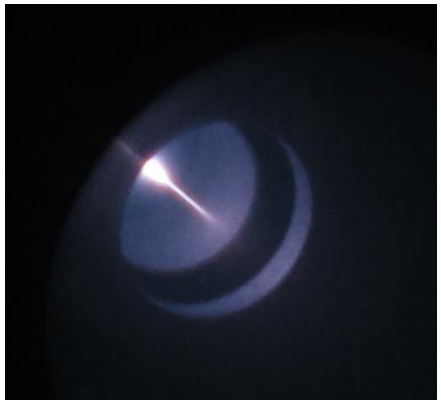
Discharge based XUV Source: Electrode geometry

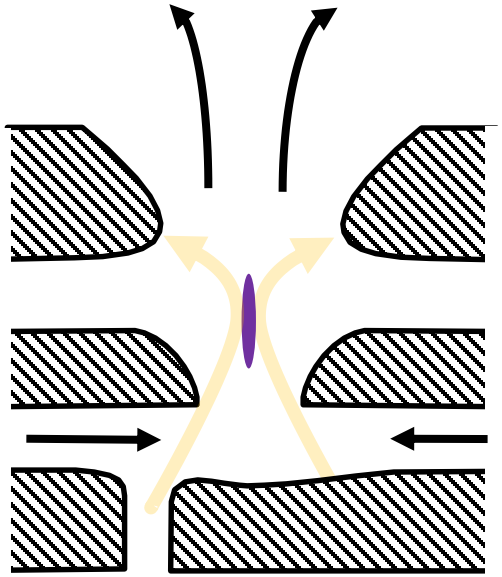


new system

- EUV generation between IP and Anode
- erosion pattern will influence EUV generation
- better understanding of relevant parameters to keep CE constant (e.g., gas flow, initial geometry)



Side view on plasma (visible)



after operation

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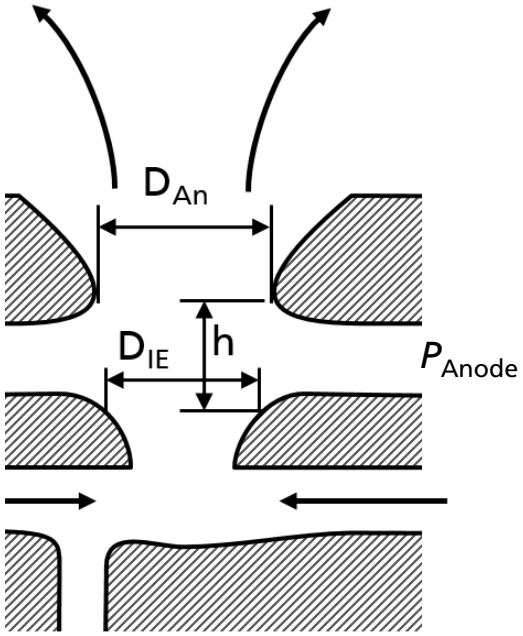
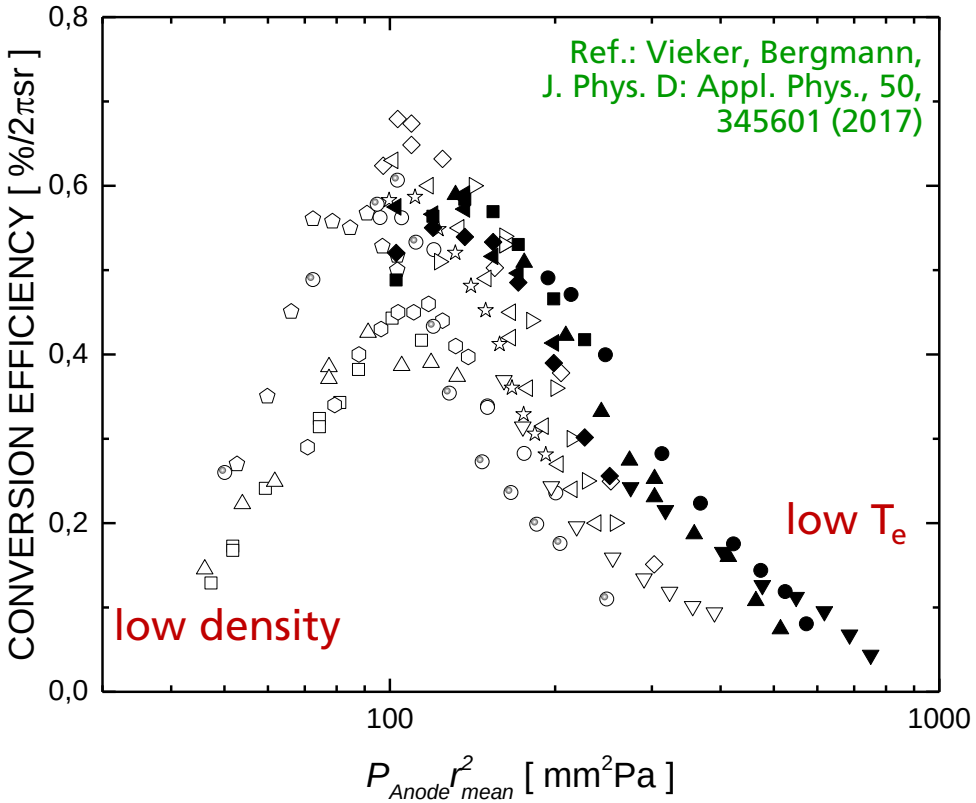
CE dependency on electrode shape



$$r_m = \frac{D_{ie} + D_{an}}{2}$$



"average line density"

$$P_{\mathrm{Anode}} r_{\mathrm{m}}^2$$

- similar CE for same "average line density"
- different values for $P_{\mathrm{Anode}} r_{\mathrm{m}}^2$ due to erosion and variation of initial diameters

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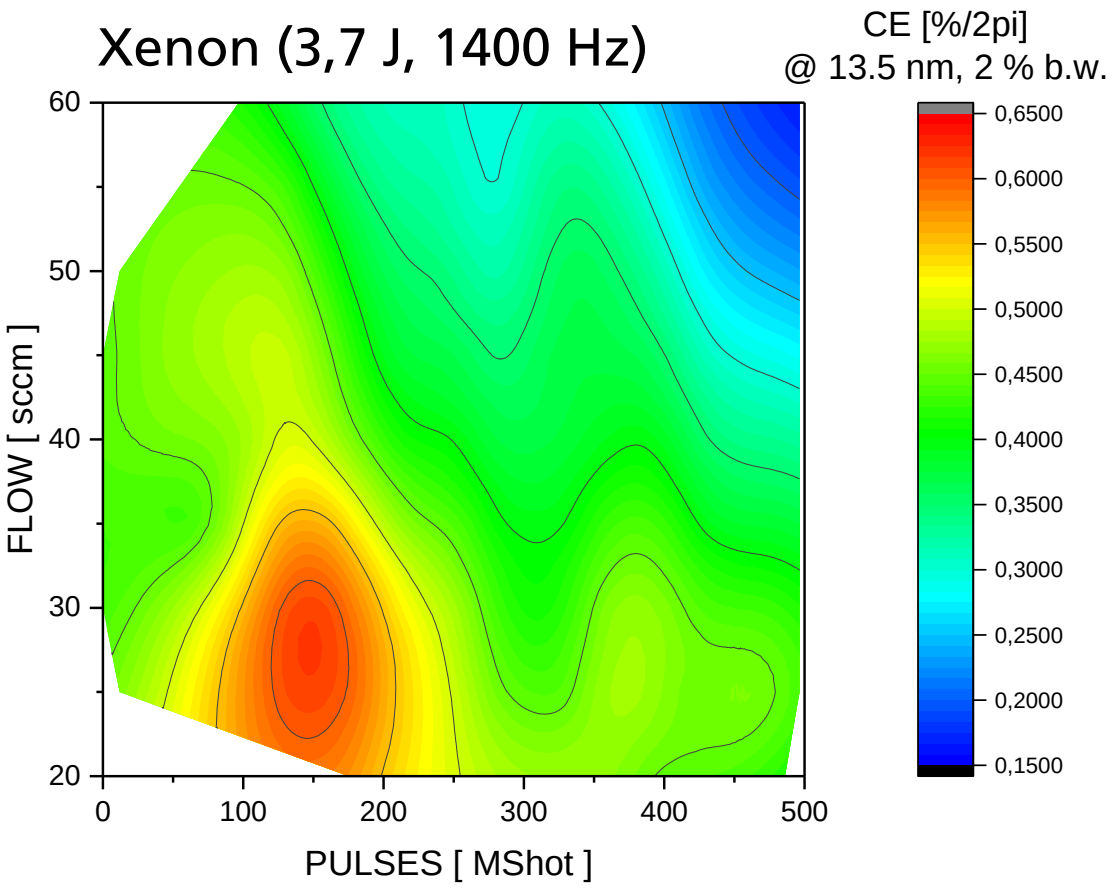
Long term behavior of conversion efficiency

- deformation of electrodes influences accessible $P_{Anode} r_m^2$
- change of CE dependence with shots in agreement with observed $P_{Anode} r_m^2$ behavior
- access of optimum $P_{Anode} r_m^2$ after 100 Mio pulses



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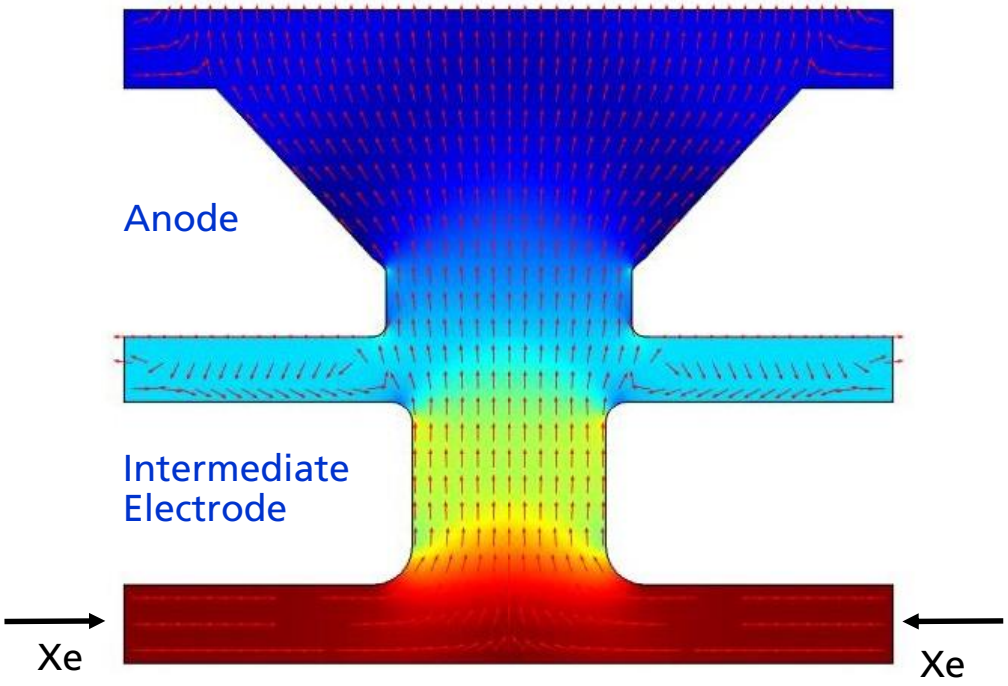
Simulation of neutral gas density distribution

- more accurate estimation of density distribution based on flow simulations
- good agreement with measured pressures at cathode and anode
- prediction of electrode shapes (erosion, initial shape) on density distribution



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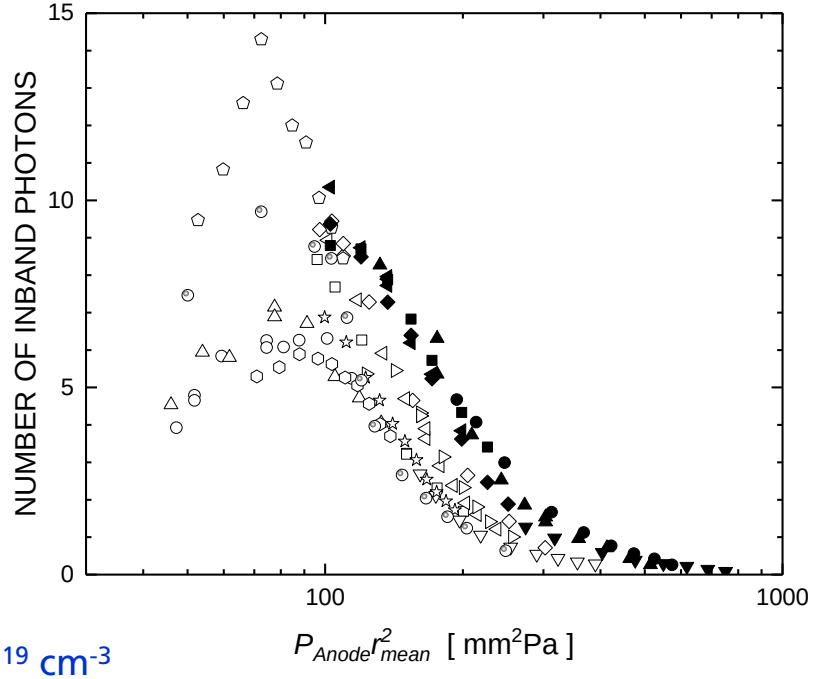
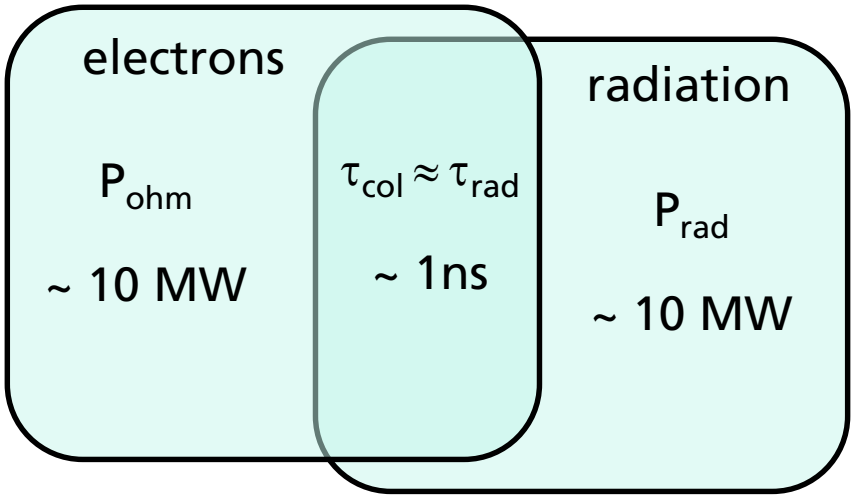
Remarks on the excitation of EUV photons…(1)

- ~100 EUV emission processes per ion
- balance of Ohmic Heating and Radiation
- state of high energy conversion
  (several %/2πsr inband at 13.5 nm)

number of 13.5 nm inband photons into 4πsr



Energy Conversion
(rough estimation)



n_e ~ 10^{19} cm^{-3}
T_e ~ 50 eV
N_{emit} ~ $4*10^{14}$
r_{pl} ~ 200 µm
I ~ 10 kA

Ref.: Vieker, Bergmann,
J. Phys. D: Appl. Phys., 50,
345601 (2017)

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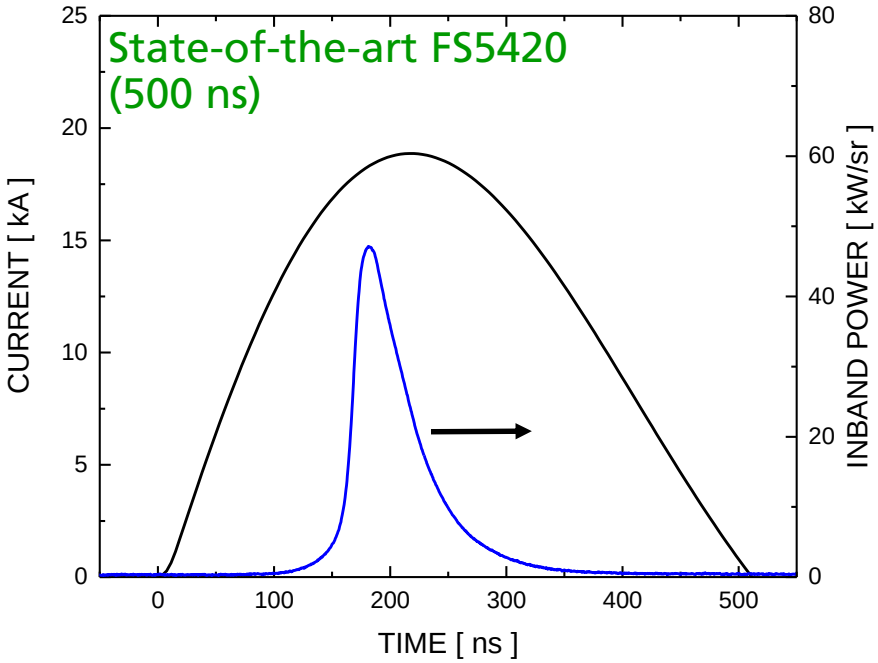
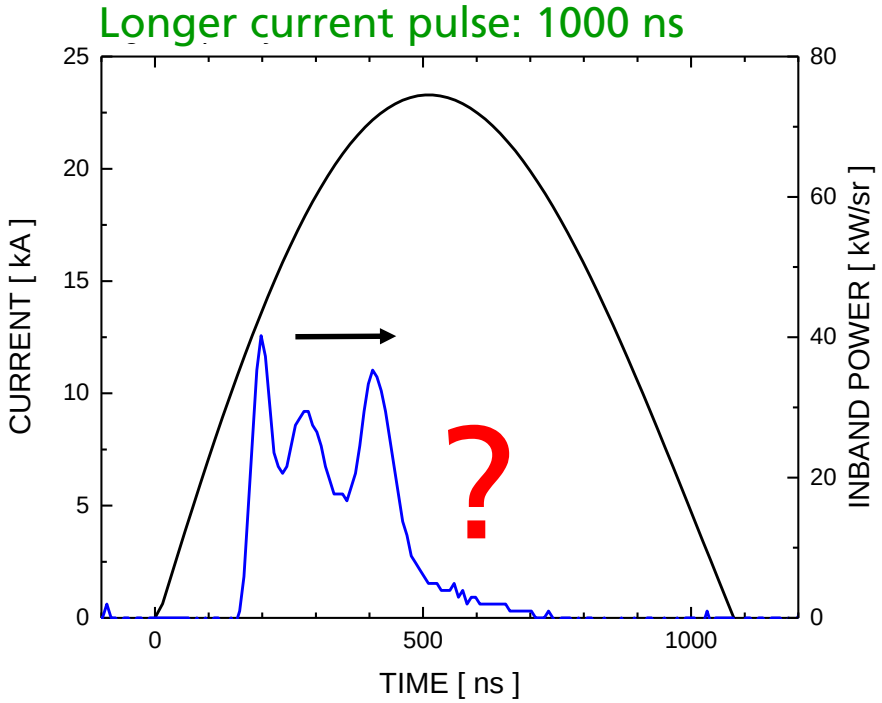
Remarks on the excitation of EUV photons…(2)



- longer EUV emission with increase of pulse duration
- decrease of EUV emission after current maximum – Reason ??
- optimization potential, if EUV emission could be prolonged



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Summary

- Emission spectra of Al, Mg as alternative emitters around 6.x nm (small bandwidth)
- Proposal of Gd/Tb based alloys for 6.x nm target material (GdCuMg with $T_m < 500°C$)

- Quantification of the correlation between electrode shape and 13.5 nm inband CE for Xenon based discharge source
- Knowledge is base for solutions to extend the maintenance interval
- Identification of further optimization potential for the CE based on more efficient use of discharge current

See also Talk/Poster:

- (S74) Laboratory Tomographic Microscopy with Compact Plasma based Extreme Ultraviolet and soft x-ray Sources, Daniel Vicario
- (S76) Spectroscopic EUV reflectometry for characterization of thin films systems and determination of optical constants, Larissa Juschkin